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# An on-farm comparison of the agronomics and economics of irrigated maize production systems in the Somali Deyr season

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**Domestic production only supplies half of Somalia's cereal requirements and more than half of the country's population is considered food insecure. In this study, the Somali Agriculture Technical Group (SATG) used an on-farm participatory research approach to compare the economic viability and plant yield parameters of an improved maize production system (SATG system) with those of the traditional farming systems (traditional system) of the Lower Shebelle region of Somalia. The SATG system included urea, diammonium phosphate, insecticide application, and a greater than average planting population. This research was conducted on seventy-seven farms located near the villages of Afgoi and Awdhegle during the 2014/15 Deyr season and was compared with results from a similar 2014 Gu season trial. Significant plant yield and harvested plant population differences emerged for crop management system, location, and season. In the 2014/15 Deyr season, implementation of the SATG system yielded 124% more grain than the traditional system (SATG = 3,970 kg ha$^{-1}$) and had 28% more plants at harvest (SATG = 37,300 plants ha$^{-1}$). Analysis of 2014/15 Deyr season cost and revenue revealed that, while production costs associated with the SATG system were higher than those associated with the traditional system, greater net revenues and profit reliability were observed for the SATG system. When plant growth and yield parameters were compared across seasons, both the SATG and traditional systems exhibited greater yields and harvested plant populations in the 2014 Gu season. In both seasons, the greatest grain yields were observed on farms near Awdhegle. As soil fertility appears to be the primary maize yield constraint in the region, these locational differences may have may have resulted from underlying locational differences in soil electrical conductivity. Throughout the Lower Shebelle, however, implementation of the SATG system appears to increase maize yields and improve farm net income.**

**Key words:** Deyr, fertility, maize, net income, on-farm, Somalia, participatory.

## INTRODUCTION

For more than twenty-five years, Somalia has struggled to overcome the political instability, civil unrest, and infrastructure collapse that occurred when the Siad Barre government fell in 1991. Today, the country relies on an informal economic system (Little, 2008) and is heavily dependent on foreign aid and development assistance

(World Bank Group, 2018). With the majority of the Somali population being rural (World Bank Group, 2016), development schemes that focus on improving rural livelihoods will likely prove most effective. One powerful rural development tool is agricultural research (Thirtle et al., 2003).

Though agriculture is hugely important to its economy, the current agricultural situation in Somalia is dire. While crop production represents up to 20% of the country's GDP (Somali Development Bank, 2015) and agriculture employs 71% of the population (CIA, 2017), domestic cereal production only satisfies around half of the population's requirements (FAO, 2012), and food can account for 80% of household expenditures (FEWS, 2014). Recognizing this, the Somali Agriculture Technical Group (SATG, www.SATG.org) is working to advance Somali agriculture through targeted crop research in Somalia's Lower Shebelle region (Figure 1). In this study, SATG used a farmer participatory research approach to compare the agronomics and economics of a new irrigated maize cropping system with those of the region's traditional maize production system.

## MATERIALS AND METHODS

Maize is the principal cereal crop in Somalia, and nearly all production takes place on the irrigated and rain-fed farmland along the Lower Shebelle river, where soils have been shaped by alluvial deposits over calcareous, unconsolidated and consolidated sedimentary formations (Jones et al., 2013; Gadain et al., 2016) and are dominated by Haplic Vertisols (70%), Fluvisols (11%), and Calcisols (2%) (Jones et al., 2013). Seasonality in the region is driven by rainfall, and maize production is restricted to two primary growing seasons: the Gu and the Deyr. The Gu season, which takes place between April and June and sees between 200 and 300 mm of rainfall (Muchiri, 2007), serves as the major growing season in the Lower Shebelle, while the Deyr season, which takes place between October and December and receives between 150 and 200 mm of rainfall (Muchiri, 2007), is the region's secondary growing season.

During the 2014/15 Deyr season, SATG utilized a multi-location randomized complete block (RCB) experimental design to compare the maize yield and growth parameters of two cropping systems: one that employed SATG best management practices (BMPs) and one that followed the traditional farming techniques practiced in the region. This research was performed on the farms of Lower Shebelle maize producers and under the supervision of SATG staff. In total, seventy-seven farmers participated in the 2014/15 Deyr season trial. Each of their farms was considered an experimental block, and each block was nested within a village (either Afgoi or Awdhegle). On each farm, one jibaal (625 $m^2$) of land was managed using the SATG system, while an adjacent jibaal was managed using each farmer's own traditional management practices.

The SATG system consisted of relatively simple BMPs: A desired SATG system plant population of 44,444 plants $ha^{-1}$ was achieved with a plant spacing of 0.75 m between rows and 0.30 m within rows; a pre-plant broadcast application of diammonium phosphate (DAP) at a rate of 200 kg $ha^{-1}$ (36 kg N $ha^{-1}$, 92 kg $P_2O_5$ $ha^{-1}$) and two 75 kg $ha^{-1}$ (34.5 kg N $ha^{-1}$) applications of urea were used to supplement soil fertility (one banded application at planting and one at the V4 growth stage); control of spotted stem borer (*Chilo partellus*) (Overholt, 2008) was achieved by applying the insecticide Bulldock® (Beta-Cyfluthrin) at a rate of 5 kg $ha^{-1}$; and timely weeding and irrigation events were performed. These BMPs were selected because they significantly increased maize yields in the 2014 Gu season, and have been repeatedly recognized as important crop production factors in other geographies (Mwangi, 1996; Asim et al., 2013). The open-pollinated maize variety "Somtux" was used in both the SATG and traditional systems, and with the exception of land preparation, which is commonly performed with a tractor in the Lower Shebelle, all aspects of field management and harvest for both systems were performed by hand.

Data were collected on each farm by taking the average of two representative 3 $m^2$ subsamples from both the SATG and traditional system plots. The main parameters of interest for this trial included the grain yield, stover yield, and plant population at harvest. Grain yield measurements were obtained after the grain had been removed from the cob and sun-dried. After drying, grain moisture measurements were taken with a handheld moisture meter, and grain weights were standardized to 15.5% moisture content. The stover was also sun-dried before weighing, but because stover moisture content was not assessed, these weights could not be standardized to specific moisture content and stover yield data must be viewed with skepticism. Further, technological availability limited the measurement precision of weights to 0.05 kg, which likely contributed to the high standard deviations observed in this trial. Plant population at harvest was assessed by hand counting.

Because the methods employed in this study were similar to those employed in the 2014 Gu season (Gavin et al., 2018), the agronomics of these crop management systems were also compared across seasons. Though similar, some methodological differences did exist between the 2014 Gu and 2014/15 Deyr seasons. In the 2014 Gu season, the SATG system had a greater desired plant population (53,300 plants $ha^{-1}$), which was achieved with a denser plant spacing of 0.75 m between rows and 0.25 m within rows, and received 50 kg $ha^{-1}$ (23 kg N $ha^{-1}$) more urea. Eighty-one farmers participated in the 2014 Gu season trial (Gavin et al., 2018).

After randomly removing the data of several farmers, a final balanced dataset consisting of seventy-four farms in each season and thirty-seven farms at each location was obtained for statistical analysis. An analysis of variance (ANOVA) was performed using the package PROC ANOVA in the statistical software SAS™ at a significance level of $\alpha = 0.05$ ($p \leq 0.05$). Mean separation was conducted using the Tukey's Honest Significant Difference (Tukey's HSD) post-hoc test (SAS, 2016).

The size of the 2014/15 Deyr season dataset also afforded the opportunity to explore potential relationships that might exist between grain yield, planting date, and plant population at harvest (for an examination of these relationships in the 2014 Gu season, see Gavin et al., 2018). Data from all seventy-seven farmers who participated in the 2014/15 Deyr season trial were used to examine the relationship between maize yield and harvested plant population, while planting date data were only available from the thirty-seven farms near Awdhegle. These relationships were evaluated via simple linear regression in R (R Core Team, 2016).

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**Figure 1**. A satellite image illustrating the location of the Afgoi and Awdhegle villages in the Lower Shebelle agricultural region of Somalia.

A farm-level economic analysis of 2014/15 Deyr season maize production in the Lower Shebelle was also performed. Utilizing data from thirty-one farmers located near Awdhegle, an ANOVA was conducted to better understand how the SATG and traditional management systems differed in terms of input costs, gross revenue, and net revenue. This analysis was completed using the PROC ANOVA package in SAS™, with statistical significance assessed at an α level of 0.05 and using Tukey's HSD for post-hoc mean separation (SAS, 2016). For the analysis, input costs were aggregated into six broad cost categories: land preparation costs, planting costs, growing costs, harvesting costs, labor costs, and capital costs. Gross revenues were determined by associating each farmer's maize yield with the average price of maize in the region, 10,000 Somali Shillings kg$^{-1}$. This figure was reported by SATG staff and falls in line with the 2015 average retail maize price, as compiled by the Famine Early Warning System (FEWS, 2015). Currency conversion into USD was conducted using the 2015 U.N operational exchange rate of 1 USD to 24,300 SOS (United Nations, 2017), making the average price of maize \$0.41 USD kg$^{-1}$.

## RESULTS AND DISCUSSION

### Grain yield

In the 2014/15 Deyr season, the grain yield of the SATG system (3,970 kg ha$^{-1}$) was 124% greater than that of the traditional system, and this pattern persisted when each location was examined independently (Table 1). The grain yield of the SATG system was 127% greater than the traditional system on farms near Afgoi (3,570 kg ha$^{-1}$) and 121% greater on farms near Awdhegle (4,370 kg ha$^{-1}$). It was also observed that farms near Awdhegle had higher grain yields than farms near Afgoi, regardless of which management system was employed. Farms near Awdhegle saw a 22% greater grain yield for the SATG system (4,370 kg ha$^{-1}$) and a 26% greater grain yield for the traditional system (1,970 kg ha$^{-1}$) than farms near Afgoi.

These locational grain yield disparities can likely be attributed to locational differences in either farm management or soil chrematistics. For the SATG system, where adequate fertilizer was supplied, these yield differences were most likely caused by locational differences in plant population. A regression analysis on the relationship between plant population at harvest and grain yield demonstrated that when adequate fertilizer was supplied, as was the case for the SATG system, greater plant populations at harvest resulted in higher yields. This relationship was not observed when soil fertility was lacking, as was the case for the traditional system (Figure 2). Similarly, planting date may influence grain yield when other constraints are satisfied but is not a yield driver in traditional, fertility limited systems (Figure 3). These results indicate that increasing plant population or planting early alone will not result in higher grain yields if fertility is lacking, and that fertility is likely the greatest yield constraint in the irrigated maize production systems of the Lower Shebelle. It also suggests that the low plant populations and elastic planting dates employed by Somali farmers in their traditional production system are appropriate given their soil fertility limitations. It should be noted, however, that these trials were not designed to explicitly study plant population or planting date effects on yield and further research is merited.

The locational differences observed for the traditional system, therefore, were likely driven by differences in soil

**Table 1.** Crop management system, location and season differences for maize grain and stover yield and plant population at harvest in the Lower Shebelle region of Somalia.

| System | Location | Season | Grain yield (kg ha$^{-1}$) | Stover yield (kg ha$^{-1}$) | Harvest plant population (plants ha$^{-1}$) |
|---|---|---|---|---|---|
| SATG | Afgoi | Gu | 3460 | 12150 | 45600 |
| Traditional | Afgoi | Gu | 2180 | 8960 | 38300 |
| SATG | Awdhegle | Gu | 5130 | 12860 | 51300 |
| Traditional | Awdhegle | Gu | 3040 | 7930 | 32600 |
| SATG | Afgoi | Deyr | 3570 | 14580 | 35600 |
| Traditional | Afgoi | Deyr | 1570 | 7620 | 30700 |
| SATG | Awdhegle | Deyr | 4370 | 12320 | 39000 |
| Traditional | Awdhegle | Deyr | 1970 | 6380 | 27600 |
| **Management system averaged across season** | | | | | |
| SATG | Afgoi | — | 3510 | 13370 | 40600 |
| Traditional | Afgoi | — | 1870 | 8290 | 34500 |
| SATG | Awdhegle | — | 4750 | 12590 | 45100 |
| Traditional | Awdhegle | — | 2510 | 7160 | 30093 |
| **Management system averaged across location** | | | | | |
| SATG | — | Gu | 4290 | 12500 | 48400 |
| Traditional | — | Gu | 2610 | 8440 | 35400 |
| SATG | — | Deyr | 3970 | 13450 | 37300 |
| Traditional | — | Deyr | 1770 | 7000 | 29200 |
| **Location and season averaged across management system** | | | | | |
| — | Afgoi | Gu | 2820 | 10550 | 41900 |
| — | Awdhegle | Gu | 4080 | 10390 | 41900 |
| — | Afgoi | Deyr | 2570 | 11100 | 33200 |
| — | Awdhegle | Deyr | 9350 | 93500 | 33300 |
| **Management system averaged across location and season** | | | | | |
| SATG | — | — | 4130$^{a}$ | 12980$^{a}$ | 42800$^{a}$ |
| Traditional | — | — | 2190$^{b}$ | 7720$^{b}$ | 32300$^{b}$ |
| **Location averaged across management system and season** | | | | | |
| — | Afgoi | — | 2690$^{B}$ | 10830$^{A}$ | 37500 |
| — | Awdhegle | — | 3630$^{A}$ | 9870$^{B}$ | 37600 |
| **Season averaged across management system and location** | | | | | |
| — | — | Gu | 3450$^{aa}$ | 10470 | 41900$^{aa}$ |
| — | — | Deyr | 2870$^{bb}$ | 10230 | 33200$^{bb}$ |
| **Summary statistics** | | | | | |
| Tukey's HSD (System) | | | 213 | 856 | 1217 |
| Tukey's HSD (Location) | | | 213 | 856 | NS |
| Tukey's HSD (Season) | | | 213 | NS | 1217 |
| $R^2$ | | | 0.71 | 0.54 | 0.75 |
| CV (%) | | | 29 | 36 | 14 |
| System (P>f) | | | <.0001 | <.0001 | <.0001 |
| Location (P>f) | | | <.0001 | 0.0294 | 0.9344 |
| Season (P>f) | | | <.0001 | 0.5700 | <.0001 |
| Season × Location (P>f) | | | 0.0023 | 0.0692 | 0.9055 |
| Location × System (P>f) | | | 0.0058 | 0.6803 | <.0001 |
| Season × System (P>f) | | | 0.0184 | 0.0065 | <.0001 |
| Season × Location × System (P>f) | | | 0.3397 | 0.1130 | 0.0506 |

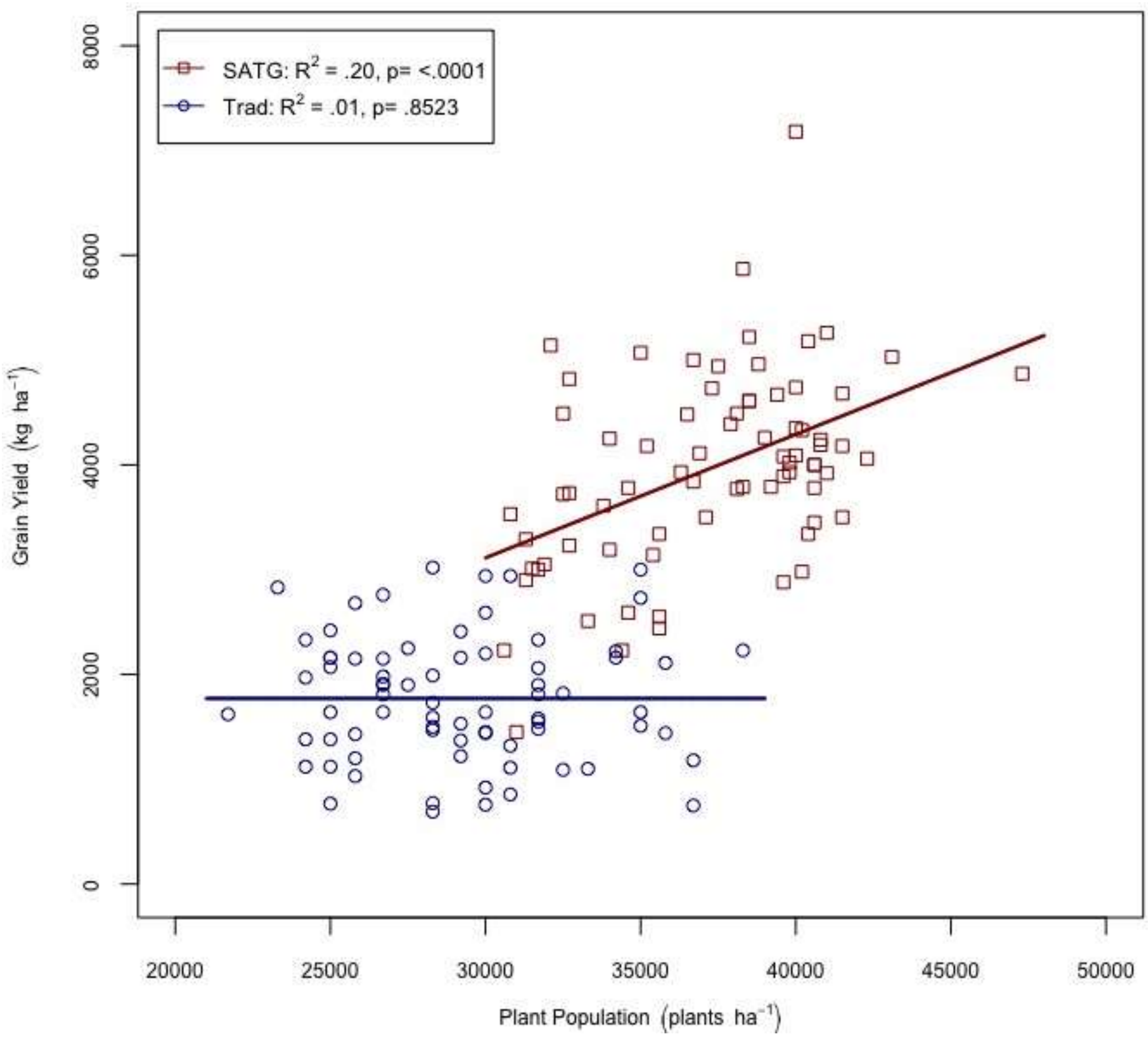


**Figure 2.** Relationship between maize plant population at harvest and grain yield on seventy-seven farms in the Lower Shebelle region of Somalia during the 2014/15 Deyr season.

fertility inherent in each location. Previous research into the soil properties of the Lower Shebelle saw significant locational differences in soil sand proportion and electrical conductivity (EC) values. Soils near Afgoi had nearly twice as much sand and a ten-fold higher EC than those near Awdhegle (Gavin et al., 2018). While the locational differences in sand proportion are unlikely to have majorly influenced plant growth in the heavily clay soils of the Lower Shebelle, the high EC values observed near Afgoi could have adversely affected crop yields by inhibiting plant development (Maas et al., 1983; Farooq et al., 2015).

Locational differences in irrigation ability could have also contributed to the locational differences in grain yield observed in this trial; farms near Awdhegle typically use gravity to move their irrigation water, whereas farms near Afgoi must often rely on diesel pumps to move water (Haji, 2017). As a result, irrigation can be costlier for farms near Afgoi, and farmers near Awdhegle may have been able to irrigate more frequently in this trial. These locational differences in irrigation practice could also be a driver of locational differences in soil EC (Jianjun et al., 2016).

When grain yield data were compared across seasons, significant interactions were observed (Table 1). The 2014 Gu season saw higher grain yields than the 2014/15 Deyr season. This was true for both management systems, but this difference was much greater for the traditional system. While the grain yield of SATG system was 8% higher in the 2014 Gu season (4,290 kg $ha^{-1}$)

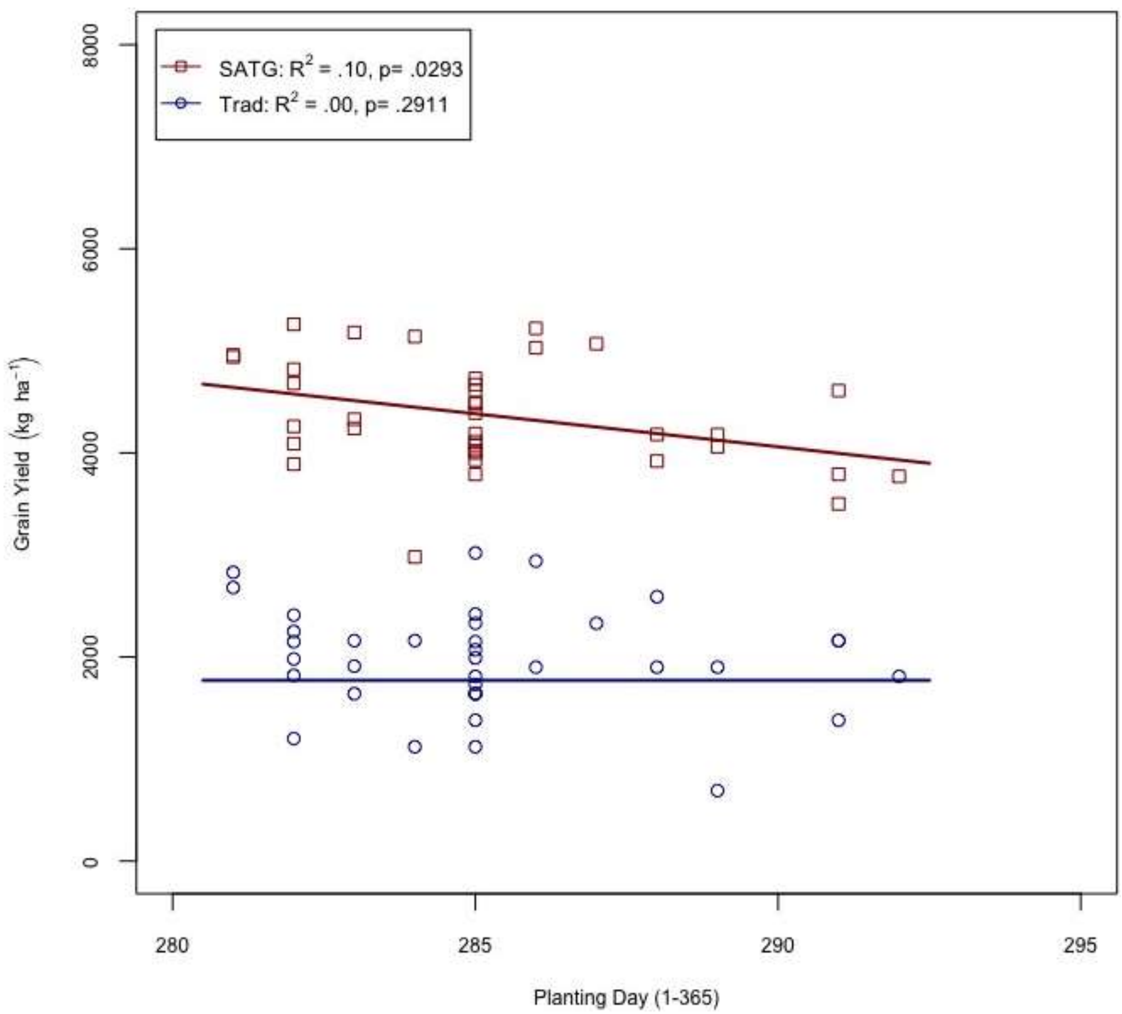


**Figure 3.** Relationship between maize planting date (January 1st = 1) and grain yield on thirty-four farms near Awdhegle in the Lower Shebelle of Somalia during the 2014/15 Deyr season.

than in the 2014/15 Deyr season, this difference was 47% for the traditional system (2,610 kg ha$^{-1}$). These differences can probably be best explained by seasonal differences in plant population for the SATG system and harsher growing conditions for the traditional system. This is because, while increasing the plant population appears to increase yields when soil fertility is adequate, that does not appear to be the case under native soil fertility constraints (Figure 2), and with the Deyr being a much drier growing season, the increased soil fertility of the SATG system may have helped to alleviate drought stress through increased root growth (Hu and Schmidhalter, 2005).

A significant season by location interaction also manifested for grain yield (Table 1). In both seasons, grain yields were higher on farms near Awdhegle than on farms near Afgoi, but this difference was much greater in the 2014 Gu season than in the 2014/15 Deyr season. Across both management systems, farms near Awdhegle saw 45% higher grain yields (4,080 kg ha$^{-1}$) than farms near Afgoi in the 2014 Gu season and just 23% higher grain yields in the 2014/15 Deyr season (3,170 kg ha$^{-1}$). The 2014 Gu season may have seen a greater magnitude difference between locational grain yields, because the locational differences in harvested plant population were much greater in that season.

When the seasonal datasets were combined, a significant interaction between season and management system was observed, but this interaction was due to differing magnitudes of system effect in each season and not inconsistencies in system effects across seasons. Across both seasons, the grain yield of the SATG system (4,130 kg ha$^{-1}$) was 89% greater than that of the traditional system, with this difference being 65% in the 2014 Gu season (4,290 kg ha$^{-1}$) and 124% in the 2014/15 Deyr season (3,970 kg ha$^{-1}$). These seasonal differences can likely be attributed to the abovementioned seasonal differences in climate, recommended plant population, and perhaps soil fertility amendments.

## Stover yield

While stover yields are here reported, these numbers should be viewed as suspect because of the abovementioned difficulties standardizing stover moisture contents. With this in mind, the stover yield trends observed in these trials still provide meaningful information about maize production in the Lower Shebelle. In the 2014/2015 Deyr season, the stover yield of the SATG system (13,500 kg $ha^{-1}$) was 92% greater than that of the traditional system, with farms located near Afgoi producing more stover than those near Awdhegle. Much of this increase in stover production can be attributed to the significantly higher plant populations recommended by the SATG system. Across seasons and management systems, the 2014 Gu season saw greater stover yields than the 2014/15 Deyr season, with seasonal differences likely resulting from plant population at harvest and moisture content differences at the time of weighing. Across both seasons, both locations, and both systems, the harvest index (HI), a measure of crop efficiency (Hay, 1995), ranged from 17% for the traditional system on farms near Afgoi during the 2014/15 Deyr season to 29% for the SATG system on farms near Awdhegle during the 2014 Gu season. In part, these low HIs can be attributed to the unimproved, open-pollinated variety of maize being grown in the region.

## Plant population at harvest

In the 2014/15 Deyr season, the SATG system had a 28% greater plant population at harvest (37,300 plants $ha^{-1}$) than the traditional system (Table 1). The magnitude of this difference, however, varied significantly between locations. On farms located near Afgoi, the plant population at harvest of the SATG system (35,600 plants $ha^{-1}$) was 16% greater than the traditional system. On farms near Awdhegle, this difference was 41% (SATG = 39,000 plants $ha^{-1}$). Both lower than expected SATG system plant populations at harvest and greater traditional system plant populations at harvest on farms near Afgoi contributed to this locational interaction. The plant population at harvest of the SATG system was 9% lower in Afgoi than in Awdhegle, while the traditional system plant population at harvest was 11% higher.

For both the SATG and traditional management systems, higher plant populations at harvest were observed in the 2014 Gu season than in the 2014/15 Deyr season. The plant population at harvest for the SATG system was 48,400 plants $ha^{-1}$ in the 2014 Gu season, 30% higher than in the 2014/15 Deyr season. This difference was 21% for the traditional system, with the traditional system having 35,400 plants $ha^{-1}$ at harvest in the 2014 Gu season. Though the plant populations at harvest of the SATG system were greater than those of the traditional system in both seasons, these differences were narrower in the 2014/15 Deyr season, which resulted in a significant season by management system interaction. Seasonal differences in plant population at harvest for the SATG system can be explained by SATG's decision to increase their within-row plant spacing recommendation from 0.25 m in the 2014 Gu season to 0.30 m in the 2014/2015 Deyr season. For the traditional system, seasonal differences in plant population at harvest are more difficult to explain. It is possible that, as the Deyr season is the shorter secondary growing season with less precipitation and warmer temperatures, farmers have learned to reduce their planting populations in order to ensure maximum time and resource efficiency.

Locational differences in plant population were more consistent across seasons, and no significant interaction was observed. In both seasons, the plant populations of the SATG system and those of the traditional system were much more closely aligned on farms near Afgoi than on farms near Awdhegle. Traditionally, farmers near Afgoi appear to plant more maize per hectare than those near Awdhegle.

## Economic analysis

The abovementioned data demonstrate that the SATG system increased maize yields in the Lower Shebelle region during both the 2014 Gu and 2014/15 Deyr seasons, but because the costs associated with new agricultural technologies often hamper their adoption (Muzari et al., 2012), it is also important to examine the economic viability of the SATG system. When production cost and revenue data were examined in the 2014/15 Deyr season, statistically significant differences were observed between the total revenues, net revenues, capital costs, labor costs, and growing costs of the SATG and traditional management systems (Table 2). In each case, the SATG system was costlier and elicited greater economic returns than the traditional system. The land preparation, planting, and harvest costs were not found to be significantly different between the two management systems. This is likely because maize farmers in the Lower Shebelle rented tractor equipment at a daily rate and relied heavily on family labor at planting and harvest time, regardless of whether the SATG or traditional system was employed.

The differences observed between the net revenue and cost of the two management systems are of particular importance to farmers. In the 2014/15 Deyr season, the growing costs of the SATG system (\$540 $ha^{-1}$) were 671% greater than the traditional system (Table 2). This cost, however, was more than compensated for by a 143% increase in net revenue over the traditional system

**Table 2.** Cost and revenue differences in USD between two maize crop management systems in the Somali 2014-15 Deyr season.

| System | Total revenue | Net revenue | Capital cost | Labor cost | Preparation cost | Planting cost | Growing cost | Harvest cost |
|---|---|---|---|---|---|---|---|---|
| | ($ ha$^{-1}$) | | | | | | | |
| SATG | 1277$^A$ | 362$^A$ | 390$^A$ | 525$^A$ | 178$^{NS}$ | 85$^{NS}$ | 540$^A$ | 112$^{NS}$ |
| Traditional | 592$^B$ | 149$^B$ | 186$^B$ | 256$^B$ | 178$^{NS}$ | 82$^{NS}$ | 70$^B$ | 112$^{NS}$ |
| HSD | 77 | 82 | 4 | 16 | NS | NS | 17 | NS |
| $R^2$ | 0.84 | 0.31 | 0.99 | 0.95 | — | — | 0.98 | — |
| CV% | 16 | 63 | 3 | 8 | — | — | 11 | — |
| System (P>f) | <0.0001 | <0.0001 | <0.0001 | <0.0001 | NS | NS | <0.0001 | NS |

($149 ha$^{-1}$). Perhaps of more importance is that the SATG system was highly reliable. In the 2014/2015 Deyr season, the SATG system did not result in negative net revenues on any of the thirty-one farms examined, whereas the traditional system resulted in economic losses for 23% of the participating farmers. The range of net revenues for the SATG system was also 8% narrower than that of the traditional system. With less variability in expected income, farmers can better plan for the future and improve long-term livelihood outcomes via investments in social capital. These economic data further bolster the argument for wide-scale implementation of the SATG system in the Lower Shebelle region.

## Conclusion

Somalia was thrust into a state of political instability and conflict when the Siad Barre government collapsed in 1991. This maize cropping system investigation represented a unique attempt to both perform applied scientific research and build domestic research capacity. Led by SATG in the 2014/15 Deyr season, this on-farm research demonstrated that Somali maize farmers can increase yields (124%) and profits (143%) by implementing the best management practices being recommended by SATG.

These conclusions echo those of maize research performed by SATG in the 2014 Gu season (Gavin et al., 2018), but that season was found to have higher grain and stover yields. While far from an exhaustive examination of Somali maize production, this research represents one of the first efforts to perform cropping system and farm-level economic research in Somalia in more than a quarter century. Future efforts should focus on determining optimal irrigation techniques, planting densities, and soil fertility requirements, as well as examining different maize germplasm.

## CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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